How bad is Reliable Multicast without Local Recovery?

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Abstract

We examine the impact of the loss recovery mechanism on the performance of a reliable multicast protocol. Approaches to reliable multicast can be divided into two major classes: source-based recovery, and distributed recovery. For both classes we consider the state of the art: For source-based recovery, a type 2 hybrid ARQ scheme with parity retransmission. For distributed recovery, a scheme with local multicast retransmission and local feedback processing.

We further show the benefits of combining the two approaches and consider a type 2 hybrid ARQ scheme with local retransmission.

The schemes are compared for up to 10^6 *receivers under different loss scenarios with respect to network bandwidth usage and completion time of a reliable transfer.*

We show that the protocol based on local retransmissions via type 2 hybrid ARQ performs best for bandwidth and latency. For networks, where local retransmission is not possible, we show that a protocol based on type 2 hybrid ARQ comes close to the performance of a protocol with local retransmissions.

Keywords: Reliable Multicast Protocol, Error Control, ARQ, FEC, Performance Evaluation.

1 Introduction

Data dissemination applications such as software updates, distribution of movies, or newspaper distribution require reliable data transfer from one sender to many receivers. The requirements for reliable multicast communications vary widely and several different protocol approaches are proposed to provide reliable multicast delivery. Therefore, it cannot be expected that a single approach is used for many different application and network scenarios. Instead, it can be expected that alternative approaches will coexist. A large number of protocols providing reliable multicast services have been presented which feature, among other differences, a large variety of error control mechanisms. Several taxonomies were presented to classify the large number of different multicast protocols (see [1, 2, 3, 4, 5]).

Multicast error recovery can be classified, dependent on the participation of group members, as:

- **Centralized error recovery (CER)** allows retransmissions exclusively to be performed by the multicast source, referred to also as **Source-based recovery**.

- **Distributed error recovery (DER)** allows retransmissions potentially to be performed by all multicast members. The burden of recovery is decentralized over the whole group.

Distributed error recovery can further be sub-classified (see figure 1), since the multicast group may be partitioned into multiple **local**[1] **groups**. In such a case, we refer to **grouped DER**, where retransmissions are performed within a local group. The absence of local groups is described by **ungrouped DER**, where retransmissions are performed by *any member* to the *global* multicast group.

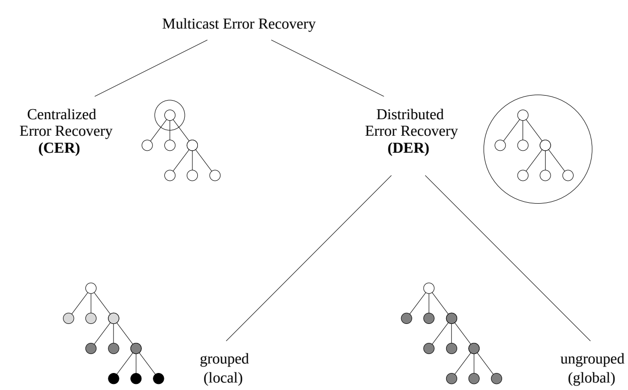

Figure 1: Classification of multicast error recovery techniques

Existing protocols and classifications can be mapped to our classification scheme in agreement with what their authors classified them as. Further there are no conflicts with other classifications [3], [4]. RMTP [6] is a protocol based on a hierarchical structure with local groups, each with a designated receiver that performs retransmissions. RMTP is a grouped DER protocol. SRM [7] allows retransmissions potentially by all nodes and proposes extensions for local recovery. Hence, SRM is an ungrouped DER protocol in our classification. In the case of the extension it is a grouped DER protocol. In NP [8] only the multicast source can perform retransmissions, so NP can be classified as CER. MESH [9] is presented as a DER protocol to

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[1] Local in the sense of neighboring in the multicast tree

both local and global recovery.

Retransmission mechanisms can further be distinguished whether original data or parity is retransmitted for loss repair. Retransmission of parity, also referred to as **type 2 hybrid ARQ** has excellent scaling properties for large groups, as different losses at different receivers can be repaired by a *single* parity packet. It leads to a significant reduction of the number of transmissions compared to retransmission of original data [8]. In [8] the retransmission of parities is also referred to as integrated FEC. Since we consider in this paper only retransmissions, we refer to parity retransmission also as FEC[2].

Based on the theory of error correcting codes [10], at the sender **parity** packets are coded from the original data packets by an erasure code based on the Reed Salomon code structure: For a group of k *original* packets that form a **transmission group** (TG for short), h different parity packets can be coded. The reception of *any* k out of those $k + h$ packets is sufficient to reconstruct the k originals. This means that whenever a loss of packets from a TG has occurred, the sender can retransmit parity packets that are used at the receivers to recover the lost original packets. Retransmitting parity packets instead of the original data packets improves the transmission efficiency, since a single parity packet can repair the loss of *any* original data packet. In particular, different data packets lost by different receivers can be repaired with the same parity packet.

Several comparisons between generic protocols of the DER class and the CER class exist. In [3] is shown that DER protocols are superior to CER protocols concerning throughput. In [11] a grouped DER and a modified ungrouped DER protocol are compared and better performance is shown for the grouped DER protocol.

The findings about hybrid ARQ type 2 [8] in the context of multicast allow now to reconsider CER protocols. In the following we will compare a CER protocol based on hybrid ARQ type 2 to a grouped DER protocol with respect to the performance in bandwidth consumption and completion time for a reliable transfer.

We further combine the two successful approaches to a grouped DER protocol with parity retransmissions and compare it to the others.

The paper proceeds as follows: Section 2 presents our model for the comparison and describes the protocols. Section 3 gives the analysis of bandwidth consumption of the different approaches. Section 4 compares the different approaches with respect to different loss scenarios. Section 5 compares the protocols for completion time. Finally, section 6 presents conclusions.

2 Model

We are looking at $1 : R$ communication and assume the multicast routing tree to be created by some multicast routing algorithm. We consider temporally independent data packet loss due to buffer overflows in network nodes of the tree. Due to in the following also to link loss. The spatial loss correlation among receivers is given by the topology of the tree model shown in figure 2. The first tree level consists of one link, the **source link**, connecting the multicast source to a backbone router. Loss on the source link is experienced by all receivers (**shared loss**). In the second tree level we have G **backbone links**, each leading via Z **receiver links** to the receivers that are located at the leaves of the tree. Therefore the tree connects $R = G \cdot Z$ receivers to the source.

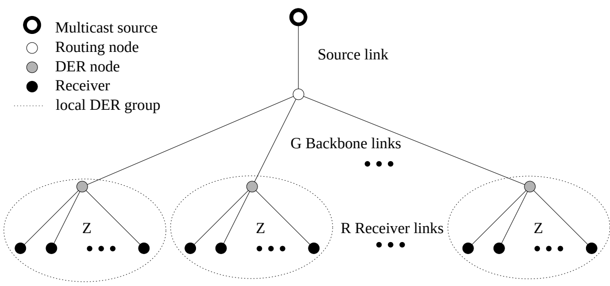

Figure 2: Tree model.

The tree is similar to the one in [11], which is based on loss measurements for Internet multicast [12] that showed that loss occurs mainly on the source link and on the receiver links and that backbone loss is negligible. Our tree model allows to model such loss, by assigning no loss to backbone links.

Figure 2 shows the tree model for DER, where Z receivers connected to the same backbone link belong to one **local group**. Each local group constitutes of a separate multicast group and the **DER node** at the end of a backbone link can perform retransmissions.

For CER the topology is the same, but only one multicast group exists that connects all receivers to the source. Local groups do not exist and DER nodes are just internal nodes that only perform routing of multicast packets.

To show the influence of loss on the different tree levels, we will examine different loss scenarios:

- *homogeneous independent loss* only on the receiver links (last hop) with packet loss probability p.
- *heterogeneous independent loss* only on the receiver links; In each of the G local groups a fraction $f_h\%$ of the Z receivers experience high loss with probability p_h, all other receivers experience loss with probability p.
- *shared source link loss* with a homogeneous loss probability p' on the source link and all receiver links.

Let d describe the constant time it takes to send a data packet over any link. With our tree model the RTT between receiver i and the source is $d_i = 6d$, between receivers i and j of the same local group is $d_{i,j} = 2d$ and the RTT between receivers i and j of different local groups is $d_{i,j} = 4d$.

[2] Usually FEC means that parity is transmitted pro-actively with the originals

Since a large number of variations is possible within the classes of CER and DER protocols, we examine such generic protocols in each class, with characteristics that have been shown to allow the highest performance for this class, up to date. For our comparison we defined one CER protocol that features hybrid ARQ type 2, one DER protocol that features hybrid ARQ type 2 and one DER protocol that features plain ARQ. We did not look at a CER protocol that features ARQ, since existing work already showed that DER/ARQ is superior to CER/ARQ [3].

For all three protocols we assume receiver-based loss detection and negative acknowledgment (NAK). Retransmissions are multicast. All protocols transmit an ADU consisting of N packets that are split into TGs of size k packets. The transmissions and retransmissions can be interleaved. Interleaving means that packets of different TGs can be transmitted intermittently. This improves the protocol throughput, since the source can use the time while it waits for feedback to transmit new packets (see section 3).

Protocol C

Protocol **C** is a CER protocol based on hybrid ARQ type 2 and feedback suppression with exponential timers [13]. Parity packets are not pre-encoded, but are coded on demand using the Reed-Solomon coder presented in [14].

Receiver-based loss detection assumes in-sequence delivery of packets, to be able to gap-based loss detection

The parameters of the feedback suppression mechanism [13] are chosen such that the expected number of feedback messages arriving at the source is in the worst case equal to the number of receivers in a local group in our tree model.

The transmission of a TG of k packets is done the following way:

The multicast source:

1. Sends the k original packets of the TG; a poll for feedback is piggybacked with the last transmitted packet to indicate the end of the TG.

2. If it is indicated by feedback from the receivers that less than k packets are received by any receiver, a_{max} new parity packets are generated and retransmitted, where a_{max} is the maximum number of packets missing out of the total number of k packets. Again, a poll for feedback is piggybacked.

3. Step 2 is repeated until no feedback about missing packets is received anymore within a certain timeout interval.

The receiver:

1. Original and parity packets of a TG are buffered.

2. If k or more packets have been received, the k originals are decoded and sent to a higher layer.

3. feedback for the TG is received, the receiver calculates the number of required additional parity packets. If the feedback suppression algorithm decides that the receiver sends feedback, it will multicast its feedback with the number of missing packets (NAK).

4. Step 3 is repeated until $\geq k$ packets have been received.

Protocol D1

We define D1 as grouped DER protocol that uses just ARQ. The source is a group leader for all the internal DER nodes in the tree model (figure 2). The internal nodes in turn are group leaders for all the receivers at the leaves. The first transmission is done to all receivers. Retransmissions are kept locally. A grouped DER scheme reduces the maximum number of feedback messages to be handled by any group leader to the number of group members. This holds in our model for the lower tree level. In the upper tree level, we assume an optimal delay-less feedback suppression mechanism to scale the number of feedback messages to be processed by the source to the number of receivers in the local groups in the lower tree level.

Protocol D1 works in a store-and-forward manner. All data first has to be received by all DER nodes on the first tree level. Then it will be forwarded in parallel from all DER nodes to the receivers at the leaves.[3]

The transmission of a TG of k packets is done the following way, either between source and DER nodes, or DER node and receivers:

The multicast source/ DER node:

1. Sends the k original packets of the TG.

2. On the reception of the NAK, the corresponding packets are retransmitted.

3. Step 2 is repeated until no NAKs about missing packets are received anymore within a certain timeout interval.

The DER node/ receiver:

1. Original packets of a TG are buffered.

2. On the detection of a loss a NAK is sent.

3. Step 2 is repeated until the TG is received.

Protocol D2:

Protocol D2 is a grouped DER protocol using hybrid ARQ type 2. The groups are set up the same way as in D1. Protocol D2 transmits a TG of k packets in the same store-and-forward manner as Protocol D1. In both steps parities are retransmitted.

[3] For delay considerations of reliable delivery to all receivers this is a worst case for distributed recovery, since it is assumed that maximum delays on both tree levels occur on one path.

We consider Bandwidth in terms of cost B of a multicast packet[4] on an average link in the multicast tree [15]. The cost of a multicast packet in a multicast group i is the product of the number M_i of transmissions per packet (original and retransmissions) and the number H_i of links traversed. Over all local groups i and $H = R + R/Z + 1$ links in total, our bandwidth measure, the **average cost of a multicast packet per link** is:

$$E[B] = \frac{1}{H} \sum_i E[M_i] \cdot H_i \tag{1}$$

To show the relative bandwidth savings of DER protocols over CER protocols, the **relative performance** $E[B_D]/E[B_C]$ of a DER protocol D and a CER protocol C is used.

3.1 Protocol C

For the CER protocol C, we have only one multicast group and all transmissions are multicast over all links. Thus we get:

$$E[B] = E[M_C] \tag{2}$$

In the following $E[M_C]$ is derived for the different cases of loss.

For homogeneous independent loss Let L_r describe the number of additional packet transmissions required by a random receiver to receive a complete TG with integrated FEC. And let L describe the number of additional packet transmissions required to have all receivers receive the complete TG, then the distribution of L and L_r and the expectation of L and M_C is [8]:

$$\begin{aligned} F_{L_r}(l) &= \sum_{i=0}^{l} \binom{k+i-1}{k-1} p^i (1-p)^k \qquad ,l = 0, \ldots & (3) \\ F_L(l) &= F_{L_r}(l)^R & (4) \\ E[L] &= E[L] = \sum_{l=0}^{\infty} (1 - F_L(l)) & (5) \\ E[M_C] &= 1 + E[L]/k & (6) \end{aligned}$$

For heterogeneous independent loss at receivers, we assume a fraction f_h of receivers to experience a higher loss p_h and the rest of the receivers to experience the lower loss p. We can directly derive from equations 3 and 4:

$$F_L(l) = (F_{L_{rh}}(l))^{R \cdot f_h} \cdot (F_{L_r}(l))^{R \cdot (1-f_h)} \tag{7}$$

where $F_{L_{rh}}(l)$ is $F_{L_r}(l)$ given by equation 3 with p_h substituted for p. $E[M_C]$ is then given by (5) and (6).

For shared source link loss in our model multicast tree we get the value of $E[M_C]$ by simulation. The loss with probability p perceived by a receiver is equally split to a loss probability p' on the source link and the receiver link:

$$p = 1 - (1 - p')^2 \tag{8}$$

[4] We do not consider feedback packets, due to their small size.

The reliable transmission of a packet from the multicast source to the G DER nodes is done via $G+1$ links with $M_{D1,G}$ transmissions. From each DER node $M_{D1,Z}$ transmissions over Z links are needed to reliably transmit a packet to the receivers of the local group. The bandwidth cost for D1 is given by:

$$E[B] = \frac{1}{H} \left(E[M_{D1,G}] \cdot (1 + G) + E[M_{D1,Z}] \cdot R \right) \tag{9}$$

For independent homogeneous loss each packet is transmitted once over all links and retransmissions are limited to the local group, such that we get:

$$E[B] = 1 + \frac{1}{H} (E[M_{D1,Z}] - 1) R \tag{10}$$

Since retransmitting originals corresponds to the retransmission of parities, if the TG size is $k = 1$ (a repetition code), equations (3) - (6) allow to calculate $E[M_{D1,Z}] = E[M_C]$, using $k = 1$ and $R = Z$. The distribution of the number $M_{D1,Z}$ of transmissions per packet in the local groups is:

$$F_{M_{D1,Z}}(m) = (1 - p^m)^Z \tag{11}$$

For heterogeneous independent loss a local group consists of a fraction f_h of receivers with high loss p_h and the rest of the receivers with low loss p. The same way as above we derive:

$$F_{M_{D1,Z}}(m) = (1 - p_h^m)^{Z \cdot f_h} \cdot (1 - p^m)^{Z \cdot (1-f_h)} \tag{12}$$

We calculate $E[M_{D1,Z}]$ again the same way as in (5) and $E[B]$ from (10).

For shared source link loss is the loss probability p' (8) the same for source link and the receiver links. Since the number of transmissions for G DER nodes behind the single lossy source link is the same as for only one DER node behind the lossy source link, we get:

$$\begin{aligned} F_{M_{D1,G}}(m) &= (1 - p'^m) & (13) \\ F_{M_{D1,Z}}(m) &= (1 - p'^m)^Z & (14) \end{aligned}$$

We calculate $E[M_{D1,G}]$ and $E[M_{D1,Z}]$ similar to (5) and $E[B]$ from (9).

3.3 Protocol D2

For D2 again the bandwidth can be calculated by separating the transmission into two independent steps. The bandwidth analysis follows the same equations as for protocol D1. Except that for $M_{D2,G}$ and $M_{D2,Z}$ parity retransmission has to be considered as for protocol C. For details see [16].

In the following the three protocols D1, D2 and C are compared for the three loss scenarios. Unless stated otherwise a packet loss probability of $p = 0.01$ is used and $R = 10^6$ receivers are in the global multicast group.

First, *homogeneous, independent loss* on the receiver links is considered. The performance of the protocols C and D2 with parity retransmission, depends on the TG size k, as shown in figure 3 for different local group sizes $Z = \{10, 30, 80\}$. The performance improves for both protocols D2 and C with an increasing TG size k. This is due to the fact that a parity packet can repair the loss of any packet out of the TG *and* that therefore a parity packet can repair the loss of different packets at different receivers. An effect that becomes more powerful with an increasing TG size k.

Figure 3 shows that the protocol D2 performs better than D1 for all transmission group sizes. A result that we experienced also for a wide range of loss probabilities and a wide range of local group sizes Z. It can be seen that the performance of D1 and D2 improves with decreasing Z, since the exposure of retransmissions to links is limited with the local group size Z.

Further is shown that even the CER protocol C achieves better performance than the DER protocol D1, if the TG size k is large enough. The reason is again parity retransmission.

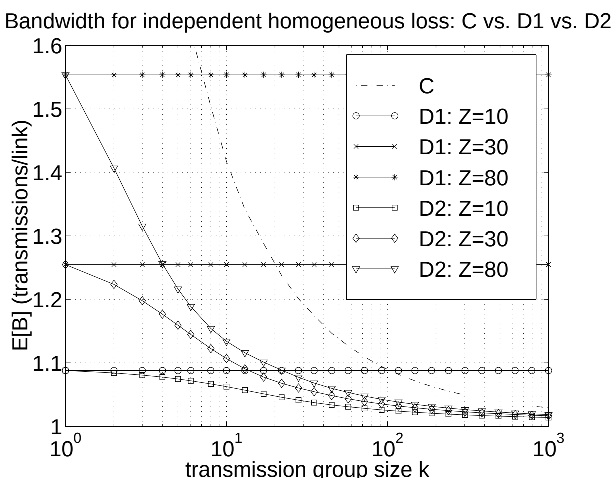

Figure 3: Bandwidth dependent on TG size k for independent homogeneous loss: C vs. D1 vs. D2, $R = 10^6$, $p = 0.01$.

In [3] the throughput performance of generic CER and grouped DER protocols is compared. From the results, it is concluded that grouped DER protocols have better scalability due to their hierarchical structure. Further it is stated that any technique employed in a CER protocol can also be employed in a local group and thus would not change anything in the relative performance. We show that this is not the case for the application of parity retransmissions and examine the relative performance DER/CER with and without parity retransmissions. The additional CER protocol C_{noFEC} is examined, which is the same as protocol C, but does not employ parity transmission.

Figure 4 shows that the relative bandwidth savings if parity retransmission is used, than without parities ($E[B_{D1}]/E[B_{C_{noFEC}}]$). This is due to the fact that protocol C performs very well due to parity retransmission; each parity packet can repair different losses at different receivers, an effect that is not exploited to the same extent in the DER case, where retransmissions are limited to a local group.

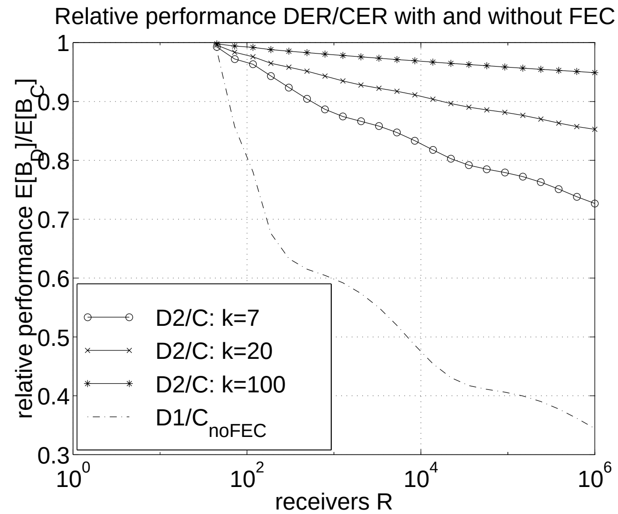

Figure 4: Relative performance $E[B]_{DER}/E[B]_{CER}$ for independent homogeneous loss with and without parity retransmission (FEC), $p = 0.01$, $Z = 30$.

Since protocol D2 outperforms protocol D1 for all parameters in the remainder only D2 will be considered and compared to the CER protocol C.

Next we will examine the effect of *heterogeneous independent loss* on the performance of D2 and C. 10% of all receivers experience a high loss probability of $p_h = 0.25$, while the other receivers experience loss with probability $p = 0.01$.

Figure 5 shows that D2 achieves higher bandwidth savings than C for heterogeneous loss, compared to homogeneous loss (see figure 4).

In the worst case for a TG size of $k = 7$ the performance of C relative to D2 decreases by almost 20%. This is due to the fact that high loss receivers dominate the required bandwidth, since retransmissions are multicast. D2 achieves better performance by restricting the influence of the high loss receivers to the local groups. The performance of D2 remains superior for all numbers R of receivers.

Figure 6 compares D2 and C for the case of *shared source link loss*, where loss happens also on the first link from the source to the backbone.

It can be seen that C improves relatively to D2 compared to the homogeneous case through shared loss. As shown in [8], shared loss for a group of R receivers can be modeled by considering a smaller group $R_{indep} \leq R$ of independent loss receivers for protocols employing FEC. Since for protocol D2 the number of receivers in a group is small already, it profits very little from shared loss. In spite of the improvement of the

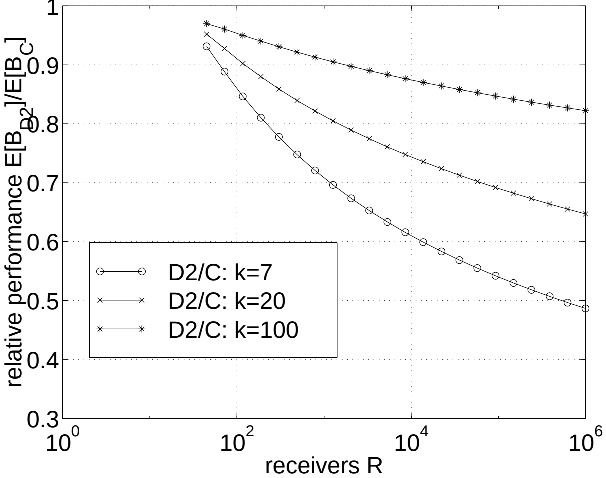

Figure 5: Relative performance $E[B]_{D2}/E[B]_C$ for independent heterogeneous loss with FEC, $p = 0.01$, $Z = 30$, $p_h = 0.25$, $f_h = 0.1$.

performance of C, D2 remains superior over the whole range of R.

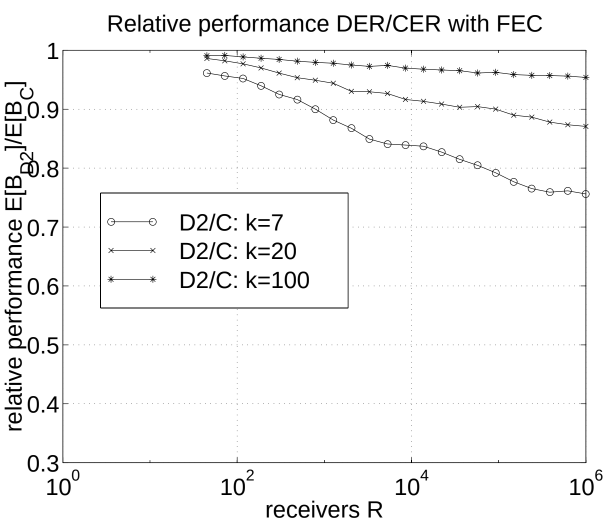

Figure 6: Relative performance $E[B]_{D2}/E[B]_C$ for shared source link loss with FEC, $p = 0.01$, $Z = 30$.

5 Latency

In the following we will give a brief overview over the latency analysis in [16]. Further, protocols C and D2 will be compared regarding the required **completion time** for the transmission of a *short ADU* [5] of length k, the TG size. The completion time is the time that is required to fully and successfully transmit the ADU from the sender to *all* receivers. To compare different sizes of k we use the average completion time per packet transmission group sizes $k \in \{7, 20, 100\}$, which correspond to typical sizes of pages in the WWW. The comparison is done for the three defined loss scenarios in which the scalability of the protocols for the number of receivers is examined.

The different contributions to the total completion time D are denoted by the following random variables:

- The gross packet **transmission delay**, denoted by D_t: this accounts for queuing delay due to flow and congestion control at the sender/DER node and is given through a constant packet throughput Λ,
- the **feedback delay**, denoted by D_f: this accounts for feedback suppression delay and additional round trip times through retransmissions rounds.
- the FEC **coding delay**, denoted by D_c
- the propagation delay, D_p.

such that we get:

$$E[D] = E[D_t] + E[D_f] + E[D_c] + D_p \qquad (15)$$

For more details about the latency analysis see [16].

The numerical results graphs for latency are ordered by loss scenario (see section 2). The scalability of the protocols is shown for all loss scenarios.

A constant transport layer packet size of $P = 2kB$ will be assumed. We did measurements with the FEC coder introduced in [17] on a SUN SPARC-20 workstation to calculate the FEC coding delay. The packet throughput is set to $\Lambda = 25pkts/s$. [6] We set $RTT = 0.1s = 6d$. The packet loss probability that a receiver sees is $p = 0.01$. The TG size will be chosen as $k \in \{7, 20, 100\}$. The local group size is $Z = 30$.

All results were calculated analytically according to the analysis in [16] and with additional simulations, using the topology given in section 2.

5.1 Homogeneous Independent loss

We now look at the scalability of the protocols in comparison. Figure 7 shows the per-packet latency $E[D]/k$ in RTT for protocols C and D2 on the ordinate, with respect to the number of receivers R.

In figure 7 it can be seen that protocol D2 performs better than protocol C over the whole range of R for corresponding TG sizes k. Both protocols scale very well with the number of receivers. The performance difference between protocol C and D2 is very small for large k. The smaller performance difference for large k is due to the fact that for larger k, a larger number of different losses can be repaired with one parity packet in the CER case and thus the number of packets to be multicast is reduced. In the DER case, the number of packets to be multicast is reduced already through the partition of the receivers in local groups and the effect of larger k is not as big.

[5] Additional results for the transfer of large ADUs consisting of $N > 10^4$ packets were derived and can be found in [16]. The results for the comparison are largely similar to the results for the bandwidth measure

[6] A throughput of $\Lambda = 25$ packets per second has been reported by Bolot [18] for a loaded IP path between Sophia Antipolis (INRIA) and London (UCL).

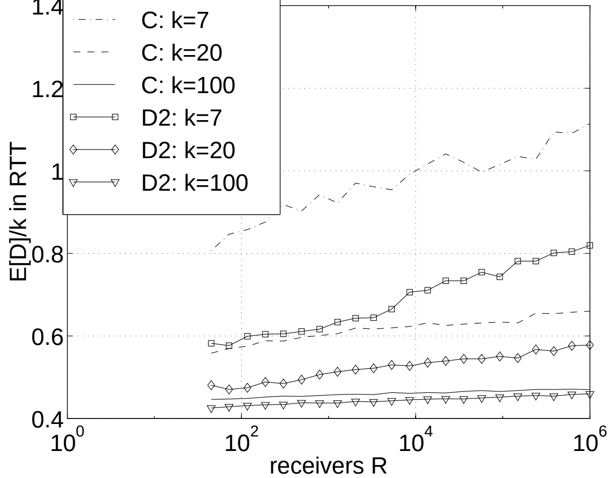

Figure 7: Completion time for independent homogeneous loss: C vs. D2, $Z = 30$, $p = 0.01$, $\Lambda = 25/s$, $RTT = 0.1s$, $P = 2kB$

5.2 Heterogeneous Independent loss

We will now examine the effect of heterogeneous loss patterns on our results from the homogeneous independent loss scenario. Figure 8 shows the per-packet latency $E[D]/k$ in RTT for protocols C and D2 on the ordinate, with respect to the number of receivers R.

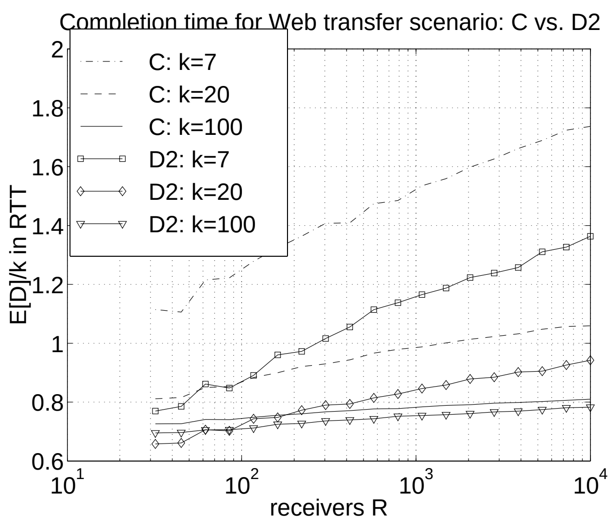

Figure 8: Completion time for independent heterogeneous loss: C vs. D2, $Z = 30$, $p = 0.01$, $p_h = 0.25$, $f_h = 0.1$, $\Lambda = 25/s$, $RTT = 0.1s$, $P = 2kB$

In figure 8 compared to figure 7 it can be seen that the relative performance of protocol C to protocol D2 for corresponding TG sizes k is hardly influenced by heterogeneity of loss. In absolute performance, both protocols have a disadvantage through heterogeneous loss. This is because the high loss receivers dominate the delay (the slowest receiver is decisive) proves slightly in relation to protocol C, since less multicast retransmissions are necessary in G parallel local groups with a small number of high loss receivers each (D2), than in one large group, including all high loss receivers (C).

5.3 Shared source link loss

We examine the influence of shared source link loss. Figure 9 shows the per-packet latency $E[D]/k$ for protocols C and D2 on the ordinate, with respect to the number of receivers R. The packet loss probability that each receiver sees is $p = 0.01$, such that the loss probability on each link is $p' = 1 - \sqrt{1-p}$.

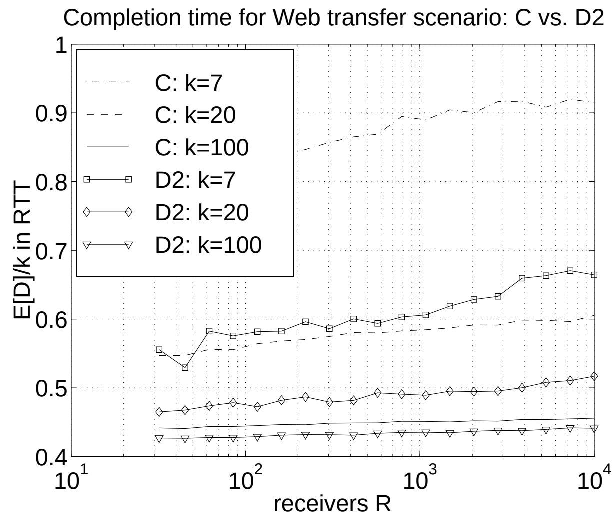

Figure 9: Completion time dependent on R for shared source link loss: C vs. D2, $Z = 30$, $p = 0.01$, $\Lambda = 25/s$, $RTT = 0.1s$, $P = 2kB$

In figure 9 it can be seen that protocol D2 performs better than protocol C for the whole range of R. Both protocols benefit from shared source link loss. This is due to the fact that for shared loss, even with retransmission of original packets, losses at different receivers can be recovered by retransmission of one original packet (see section 3). Protocol D2 profits more from shared source link loss than protocol C. The benefit through shared source link loss for both protocols is smaller for large TG sizes k than for small k.

6 Conclusion

We compared three generic reliable multicast protocols. Two of them (D1 and D2) with additional structure that allows to limit retransmission to a local scope. One protocol C that allowed only retransmissions from the source. C and D2 were protocols with parity retransmissions, while for D1 originals were retransmitted. Our conclusions from the comparison with respect to completion time of a reliable transfer and the bandwidth needed are as follows:

- D2 outperforms D1 and C in terms of completion time and bandwidth.

ceivers, the performance of C decreases more than the performance of the DER protocols.

- Applying hybrid type 2 ARQ to protocols with local groups does not yield as high a performance gain, as applying it to protocols without local groups.

- For large transmission group sizes k, the performance of C comes close to the performance of D2.

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